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Thomas, Richard, Holmes, Matilda and Morris, James ORCID: 0000-0002-5756-0362 (2013) "So bigge as bigge may be": tracking size and shape change in domestic livestock in London (AD 1220-1900). Journal of Archaeological Science, 40 (8). pp. 3309-3325. ISSN 0305-4403

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<http://dx.doi.org/10.1016/j.jas.2013.02.032>

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Accepted Manuscript

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PII: S0305-4403(13)00088-5

DOI: [10.1016/j.jas.2013.02.032](https://doi.org/10.1016/j.jas.2013.02.032)

Reference: YJASC 3621

To appear in: *Journal of Archaeological Science*

Received Date: 12 November 2012

Revised Date: 25 February 2013

Accepted Date: 27 February 2013

Please cite this article as: Thomas, R., Holmes, M., Morris, J., “So bigge as bigge may be”: tracking size and shape change in domestic livestock in London (AD 1220-1900), *Journal of Archaeological Science* (2013), doi: 10.1016/j.jas.2013.02.032.

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Highlights

- Synthesis of nearly 8000 measurements of cattle, sheep, pig and chicken from AD1220-1900 London
- Multiple episodes of size increase identified, the speed and timing varied by species
- Earliest evidence of changes in cattle and sheep occur in the early 14th century and may reflect the impact of disease events in the first half of that century
- Later increases in livestock size occurred as a consequence of agricultural innovations in the wake of the Black Death and the increasing commercialisation of animal farming, as the meat requirements of an expanding London grew.

Title: “So bigge as bigge may be”: tracking size and shape change in domestic livestock in London (AD 1220-1900)

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Abstract

This study presents the analysis of 7,966 individual cattle, sheep, pig and chicken bone measurements from 105 sites excavated in London dating to the period AD 1220-1900. Multiple episodes of size change are identified, although the speed and timing varies by species. The earliest evidence for size change in cattle and sheep occurs in the early 14th century and may be connected to the need to restock livestock populations following the outbreaks of murrain in the first half of that century. Subsequent size increases in livestock size may have occurred as a combined consequence of agricultural innovations in the wake of the Black Death, the increasing commercialisation of animal farming, as the meat requirements of an expanding London grew, and the rise of the ethic of improvement.

Key words

Domestic livestock, breeding, London, medieval, post-medieval

1 Introduction

Over the past 40 years, the analysis of animal bone measurements from archaeological sites dating to the medieval and early modern periods in Britain has incrementally shed new light on spatial and temporal variation in the size and shape of domestic livestock. These studies have revealed increases in livestock size occurring from the 14th to the 19th centuries (Thomas 2009, 138); however, the picture is complex. There is a great deal of regional variation, with outlying sites generally experiencing later developments than central localities (Davis and Beckett 1999). Moreover, there is considerable variation in the timing of size changes, both within and between species; at some sites the changes occur over a short period of time, while at others it is a much more gradual affair. Taken together, this evidence adds weight to the view held by many economic historians (e.g. Allen, 1991, Allen, 1999, Beckett, 1990, Clark, 1999, Havinden, 1961, Jones, 1965, Kerridge, 1967, Thirsk, 1987) that innovations in agriculture and rising output and productivity occurred as part of a long-term and gradual process of agricultural change, with significant changes occurring in the 16th and 17th centuries, rather than as a singular revolution in the late 18th and early 19th century (e.g. Prothero 1888, 1912, Overton 1996). Progressive reviews of the zooarchaeological contribution to this debate are provided by Albarella and Davis (1996), Davis (1997), Davis and Beckett (1999), and Thomas (2005a, 2005b). Most recently, the identification of size increases in cattle, sheep, pig and domestic fowl, at the site of Dudley Castle, West Midlands, has raised the possibility that in some places these changes may have stemmed from

agricultural, landscape and tenorial reorganisation in the wake of the Black Death (1348-1350) (Thomas, 2005a, 2005b). While this archaeological evidence has made an important contribution to current debates in agricultural history, there is an important gap in our knowledge: the nature and timing of livestock improvement in the sites supplying the most important centre for meat consumption in Britain in this period - London. The aim of this study is to fill this gap through the analysis of a large, un-synthesised dataset of animal bone measurements generated by Museum of London Archaeology. This permits the exploration of size and shape change in cattle, sheep, pig, and chicken in the period AD 1220-1900, within the city and its environs, making a major new contribution to livestock history. In doing so it satisfies two identified research objectives for the city of London – undertaking a “regional synthesis of breeding programmes” and “developing the potential of environmental data to inform us of...economic change” (Nixon, et al., 2002) – and realise the potential of post-medieval animal bones in London, which have remained largely unexplored (Schofield, 2000, 2011). Furthermore, during the period encompassed by this study, animals were increasingly driven to London from all over the country; consequently, this study potentially provides a snapshot of livestock breeding practices beyond the immediate hinterland of the city.

2 Materials and Methods

Since the early 1990s Museum of London Archaeology (MOLA; formally Museum of London Specialist Services and Museum of London Archaeological Service) has systematically recorded zooarchaeological data from developer-funded excavations in London in a single zoological database. Included amongst this dataset is an enormous archive of previously un-synthesised animal bone measurements taken using the standard set forth by von den Driesch (1976).

In this study, metrical data from 105 multi-period sites with contexts dating AD 1220-1900 (Figure 1, Table 1) were analysed. To assist in the spatial analysis of these data five regional groupings were identified: Greater London (all sites outside the main conurbation of the medieval city, most situated along major medieval roads); Northern suburbs (areas of Islington and Hackney); City (sites mainly within the city walls); Southwark; and Westminster. Throughout this time period London underwent dramatic change and urban development (Schofield 2011); however, with the exception of the Greater London sites, the assemblages utilised in each period are from sites within an urban environment.

To facilitate the identification of temporal trends and accommodate the majority of the data, bone measurements were placed into eight overlapping phases (Table 1). Two sub-phases of phase A (A1: 1220-1300; A2: 1230-1350) and B (B1: 1340-1450; B2: 1400-1500) were also introduced to explore diachronic variation immediately before and after the Black Death. Broadly dated and unsecurely dated assemblages (indicated by the presence of residual pottery) were excluded from the analysis, under the presumption that bones and pots shared comparable taphonomic pathways. By using the pottery data to take into account residual deposits all mixed-dumping deposits were excluded. The majority of the assemblage, 78% (6,211), comes from cut features with the remainder originating from undisturbed layers. Despite these precautions, the deeply stratified and complex nature of London's archaeology means it is impossible for any study to guarantee that no bones were redeposited. However, the use of only securely dated undisturbed contexts combined with the large sample size limits the effects of redeposition and justifies the use legacy data and the production of synthetic analyses of metrical data.

Data were included from cattle (*Bos taurus* L., 1758), sheep (*Ovis aries* L., 1758) and sheep/goat (*O. aries/Capra hircus* L., 1758), pigs (*Sus scrofa domesticus* Erxleben, 1777) and domestic hen (*Gallus gallus domesticus* L., 1758). Bones identified as goat were not included to reduce the influence of differences in the morphology between sheep and goats. It is conceivable that some goat bones were included in the sheep/goat category, but as sheep far outnumber those of goat throughout the period (Albarella, 1999), and because their bones were positively identified from assemblages at a ratio of 7:1, the biasing effect is considered negligible. Similarly, galliformes such as guinea fowl (*Numida meleagris* L., 1758), pheasant (*Phasianus colchicus* L., 1758) and black grouse (*Tetrao tetrix* L., 1758) are morphologically similar to domestic hen (Tomek and Bocheński, 2009). However, domestic hen was far more commonly identified – only six pheasant bones and no guinea fowl or black grouse were recorded for the period under scrutiny – so it is assumed that the majority of fowl bones derive from domestic hen. It is also worth noting that the discrimination of morphologically-similar taxa was achieved using the same methods and reference material by MOLA zooarchaeologists, if discrimination was not possible, elements were recorded under general categories (i.e. chicken sized); thus, the possibility of inter-observer inconsistency was minimised.

Not all bone measurements recorded in the database were used in this study; this partly reflects the infrequency of some measurements, but also their variable reliability. Only fused mammal and adult bird bones were included; furthermore, late-fusing epiphyses were preferred to minimise the effect of post-fusion growth in early fusing bones (Davis, 2000, Popkin, et al., 2012). Where possible, dimensions in three anatomical planes (length, breadth and depth) for each bone were included, utilising the most abundant measurements available where there was the potential for more than one to be used. The anatomical elements selected depended on the potential usefulness of measurements likely to be taken. From the axial skeleton only horncores were included for analysis (greatest and least diameter of the horncore base, basal circumference, and length of the outer curvature of the horncore). The latter measurement was used to classify horncores into four size categories (after Sykes and Symmons, 2007). Maxillae, mandibles and pelves were excluded as measurements were not available in three planes and the best discriminators of sex (Greenfield, 2006) were not taken; unfortunately, virtually no tooth measurements were recorded in the database. With regards to the appendicular skeleton, scapulae were discounted because of the effects of post-fusion growth. Phalanges were also excluded as they are often subject to plastic deformation as a consequence of age, sex and lifestyle (Bartosiewicz, et al., 1997), and there are size differences between anterior and posterior elements (Dottrens, 1946), a distinction not made in the archaeological material. A list of the post-cranial bone measurements included in the analysis is provided in Table 2.

To maximise the potential of the metrical data, and facilitate the inclusion of data from small-scale archaeological interventions (Appendix 1), log-scaling was employed so that different measurements could be compared on the same axis. This technique involves converting all measurements to base-10 logarithms by relativising each against a standard (Albarella 2002; Meadow 1999; Simpson, et al., 1960). A positive value indicates that the archaeological specimen is larger than the standard, a negative value that it is smaller, while zero indicates that the standard and archaeological specimens are identically sized. Wherever possible, measurements taken in the same anatomical plane were combined, because these are highly correlated (e.g. Davis, 1996); where samples were small, all post-cranial bones were combined on the same axis, although loss of data resolution will have inevitably resulted.

Since diachronic changes in animal shape and size may reflect a changing balance between males, castrated males, and females, it is necessary to determine the sexual composition of

the combined assemblages. Determination of sex ratios in cattle was carried out using size-independent scatter plots of metacarpal measurements (Albarella, 1997a). Analysis of shape differences in sheep metacarpals was undertaken using a slenderness index (Davis, 2000, Guintard and Lallemand, 2003). Metacarpals were chosen because they are the most sexually dimorphic bone (Bartosiewicz, 1987, Higham, 1969, Thomas, 1986). Horncores over 195mm long were analysed for sex differences following Sykes and Symmons (2007); unfortunately, there were insufficient data to investigate this aspect of the sheep assemblage. Distinction of hens and cockerels was carried out using the tarsometatarsus, combining both the presence/absence of a spur or spur scar, with length and breadth measurements following Sadler (1990) and West (1985).

The statistical significance of spatial and temporal differences in post-cranial bone measurements was determined using the non-parametric Mann-Whitney U-test, in recognition of the fact that sample sizes were unequal and the data for most phases were not normally distributed.

3 Results

3.1 The dataset

In total, nearly 8000 individual measurements met the criteria for inclusion in this study. The distribution of these measurements by taxon and phase is set out in Table 3. From these data it is apparent that some phases are better represented than others; notably, it is clear that fewer biometrical data has been collected for the 18th and 19th centuries. This partly reflects the emphasis of archaeological enquiry (Thomas, 2009), but also testifies to the presence of livestock that matured faster and could be slaughtered before bone fusion was completed (thus rendering them ineligible for this kind of study). Some taxa are also better represented by measurement data than others; pig measurements were rare, a consequence of their relatively lower abundance on medieval and post-medieval sites, and the fact that they were typically slaughtered before skeletal maturity was reached (e.g. Albarella, 2006). Finally, it should be noted that post-cranial bone length and breadth measurements are far better represented than depth measurements (Tables 4, 6, 8, 10), hampering the comprehensive analysis of shape change over time.

3.2 Spatial analysis

Before exploring temporal differences in the size and shape of livestock supplying London in the late medieval and post-medieval, it is necessary to consider the influence of broad-scale spatial differences, and also the impact of individual sites on the data collected. Spatial analysis might, for example, permit the identification of differences in the conformation and appearance of livestock that reflect supply networks, which in turn might be linked to social standing: high-status sites were generally located in the centre of the city (such as the guildhall) and Westminster; the theatre and some poor sites are all in Southwark; and the poorer urban areas are situated in the northern suburbs.

3.2.1 The contribution of individual sites

As Appendix 1 illustrates, only a small number of sites have contributed notably large numbers of post-cranial bones in particular phases for cattle and domestic hen. Large concentrations of cattle metapodials with relevant measurements were recovered from two sites: STE95, 250 Bishopsgate ($n=211$; all from phase B2) and SRP98, Spitalfields Market ($n=253$; spread mostly across phases E, F and G), both part of the Spitalfields excavations. Accumulations of metapodials (and also horncores) at these sites arose from craft-activity. Comparison of the size of post-cranial bones from phase B2 at STE95 with contemporary sites reveals them to be larger in length ($U=663$; $P=0.040$) and breadth ($U=791$; $P=0.000$) (Figure 2). This appears to reflect the deliberate selection of the larger bones of male cattle for working: the cattle at contemporary sites display a bimodal distribution indicating the inclusion of male and female animals, while the cattle measurements from STE95 display a unimodal distribution. To avoid the biasing effect of the inclusion of so many male cattle from phase B2 at STE95, they have been excluded from the proceeding analysis of temporal variation in cattle size.

The biometric influence of the cattle from SRP98 is only possible to confidently assess for breadth measurements due to the paucity of length and depth measurements. Nevertheless, the available data indicate no statistically significant difference between cattle breadth measurements from SRP98 and contemporary sites in phase E (1600-1700) ($U=569$; $P=0.8599$), phase F (1650-1725) ($U=126$; $P=0.106$) and phase G (1700-1800) ($U=369.5$; $P=0.8161$). However, in the absence of other dimensions one cannot exclude the possibility of equifinality: young bulls, old cows, and castrated males at various ages may look similar in this particular dimension.

The site of Merton Priory (MPY86) contributed the largest single collection of domestic hen bones ($n=127$), of which the majority ($n=84$) came from Phase A (1220-1300). Comparison with other Phase A domestic hens, reveals the Merton Priory specimens to be greater in breadth ($U=2583$; $P=0.002$) and depth ($U=128$; $P=0.006$), but not in length ($U=1006$; $P=0.906$). These differences are unlikely to result from differences in sexual composition, since length should be affected; it is therefore speculated that either at least two different shapes of domestic hen were being supplied to sites in medieval London or that Merton Priory kept their own flock.

3.2.2 Spatial analysis

Comparison of log-scaled cattle, sheep, and domestic hen bone measurements between sites within the city and the wider hinterland (Greater London), was only possible when all post-cranial bones were combined. While statistically-significant differences were detectable, the picture is complex (Table 4). Cattle within the city were larger than those from the hinterland in phases B, D and E, perhaps suggesting the selective supply of larger animals (or a greater proportion of males) to the London markets; however in phases A and G, the cattle in the hinterland were larger than those within the city. The sheep in the city were only larger than those in the hinterland in phase B. Only in phases C and H were domestic hens larger within the city than in the hinterland.

Comparison of size variation in livestock between the different areas within the city was only possible for cattle and sheep; this revealed few differences. The cattle in the Northern Suburbs were statistically-significantly larger than those in the City and Southwark in phase B, the cattle in Westminster in phase E, and the cattle in the City in phase F. It is likely that this phenomenon reflects the fact that the Northern Suburbs cattle dataset for these phases included the bone-working sites around Spitalfields, which included larger male animals (see above). The only detectable differences with respect to sheep was the presence of statistically-significantly larger animals in the Northern Suburbs: in phase B and D compared with animals in the City (the sheep from the City were also larger than the sheep in Southwark in phase D); in phase E and F in comparison with sheep in Southwark; and in phase H compared with Westminster. While more sites contributed to the Northern Suburbs dataset for sheep than was the case for cattle, STE95 and SRP98 were important contributors.

Comparison of the phase B, D, E, F and H data from these two sites, with contemporary sites situated in the same region, revealed the average to be greater at STE95 and SRP98, with the exception of phase B (Figure 3).

3.3 Diachronic change in size and shape

3.3.1 Cattle

Analysis of the post-cranial bones of cattle reveals an increase in mean size from the early 14th century to the 17th century (Figure 4, Table 5), although not all changes between consecutive phases have statistical significance (Table 6). A consistent change in lengths, breadths and depths occurs between phase A (1220-1350) and phase B (1340-1500). When broken down by sub-phase (Figure 5, Table 6), it is evident that this size increase occurs in the first half of the 14th century (between phase A1 (1220-1300) and A2 (1230-1350)), although it is only statistically significant ($P < 0.05$) for lengths and depths. No significant increase in size is evident between A2 and B1 and between B1 and B2.

Further statistically-significant size increases in breadths occurred between phases D (1550-1600) and E (1600-1700), and E (1600-1700) and F (1650-1725) (Table 5). An increase in depth measurements also occurred between phase B (1340-1500) and C (1450-1600). The small size of the post-17th-century dataset makes it difficult to be certain about changes in cattle size in the later post-medieval period. However, the currently available evidence indicates no significant change in size, indeed mean length, breadth and depth measurements are all smaller in the 19th-century cattle (Figure 4, Table 6).

Analysis of temporal change in cattle horncore size for those phases with sufficient data, reveals that prior to the 16th century, cattle were characterised as having ‘small’ and ‘short’ horns (Figure 6). From the middle of the 16th century, however, it is ‘medium’ and ‘long’ horns that predominate.

3.3.2 Sheep

The post-cranial data for sheep exhibit a gradual increase in average breadths, depths and, to a lesser extent, lengths throughout the entirety of the study period (Figure 7, Table 7). Statistical analysis of these data (Table 8) reveals that the differences in breadths is statistically-significant except for between phases E (1600-1700) and F (1650-1725), although given the fact that these two phases overlap by 75 years this is perhaps unsurprising.

Four of the length increases are statistically significant, only one average increase in depth is statistically significant, between phases D (1550-1600) - E (1600-1700), making this the only phase when a statistically-significant increase in all three anatomical planes occurred.

3.3.3 Pig

The much smaller size of the pig dataset (Table 9) means that meaningful differences can only be discerned by combining all log-scaled post-cranial bone measurements on the same axis. Based purely on means, a gradual increase in size from the 14th century through to the early 18th century is apparent (Figure 8); however, the differences in sample composition are not statistically-significant between consecutive phases (Table 10). Nevertheless, when the data are grouped into larger temporal units, statistically-significant differences are apparent (Table 10): one episode of size increase occurs in the 16th century and another in the 17th or early 18th century.

3.3.4 Domestic hen

A major increase in the size of domestic hens in all three anatomical planes – although only statistically significant for lengths and breadths – occurred between sub-phases B1 (1340-1450) and B2 (1400-1500) (Figure 9, Tables 11-12). Mean size increases in lengths, breadths and depths also occurred between phases B (1340-1500) and C (1450-1600) and phase G (1700-1800) and H (1800-1900) but these were not statistically significant.

3.4 Changes in sexual composition

Before interpreting temporal variation in size changes in domestic livestock it is necessary to establish whether or not they arose as a result of changes in the balance of sexes within the herds/flocks. Such changes could arise from changing agricultural emphasis; however, cautious interpretation is required since the bones available for study originated from consumption refuse.

3.4.1 Cattle

Size-independent analysis of cattle metacarpal measurements is hampered by the small number of complete metacarpals, which has necessitated the combination of data for the later phases (Figure 10). As Albarella (1997a) has demonstrated, in a single population differences in the shape of males, castrated males, and females should appear on the same regression line, with intact males being more robust in both the distal breadth and shortest diameter of the

shaft than females, and castrates exhibiting greater lengths but narrower breadths than intact males, because of delayed epiphyseal fusion. Following this logic, the majority of the sample from London would appear to represent males (most probably castrates). The fact that a greater proportion of the phase A (1220-1350) cattle plot towards the bottom left-hand corner could indicate relatively more cows in this phase, while a greater proportion of more robust male cattle in phase B (1340-1500) is apparent. This is primarily driven by the inclusion of a large number of male cattle from a site of bone working (STE95) (Figure 2). In later phases there are no clear differences in the proportional shape of the cattle over time. These interpretations must be considered with caution, however, since the data derive from more than one population and sex is not the only variable that influences metapodial shape: pathology, 'breed', and age also play a role (Albarella 1997a).

Analysis of sexual dimorphism using cattle horncores was only possible for phases D (1550-1650), E (1600-1700), and F (1650-1725), when horncores with measured lengths over 195mm began to appear (Figure 6). Only two sites contributed to this analysis: STE95, 250 Bishopsgate (n=258); and SQU94, Spitalfield Market (n=30). Analysis of these data support the view from the metacarpals, that the majority of cattle supplying London were male (Figure 11): no clear temporal differences in sexual composition are evident.

3.4.2 Sheep

Analysis of sheep metapodial shape using the slenderness index (after Davis, 2000), indicates the presence of increased numbers of thicker (broader) specimens in the period 1600-1725 (Figure 12). While this could indicate greater numbers of males, these data may have been influenced by sheep morphotype. Superimposition of the boundaries separating small/tall and slender/thick sheep (after Guintard and Lallemand, 2003), reveals that the majority of sheep in all phases plot within the small/slender group; nevertheless, by the post-medieval period there is evidence for a greater diversity of shape, which included the presence of tall/slender, and small/thick sheep. This trend accords with O'Connor's (1982) study of modern sheep of known breed, which demonstrates a correlation between robusticity and 'improvement', and is consolidated further by a clear increase in the coefficients of variation for metacarpal breadth measurements (Table 13), which far exceed the values observed at other post-medieval sites (Popkin et al., 2012).

3.4.3 Domestic hen

Analysis of sex in domestic hens reveals a predominance of hens (indicated by their small size and lack of spur), but an increase in the proportion of males in phase B (1340-1500) and again in phase E (1600-1700) (indicated by their large size and, in the case of cockerels, the presence of spurs or spur scars), although the sample size for the latter phase was very small (Figure 13). The size increase between phases A (1220-1350) and B (1340-1500) may thus be partially attributed to changing sexual balance of the domestic hens supplied to London, but thereafter there are no other sex-size correlations.

4 Discussion

The analysis of nearly 8000 individual bone measurements from 105 mainly urban sites from London dating to the period 1220-1900 has added to the growing body of evidence that changes in the size of livestock occurred throughout the later medieval and early modern period. Furthermore, this study reveals that the timing of these changes varied by species; in most instances these do not appear to reflect changes in the sexual composition of the slaughtered population, although exceptions are discussed below. It is also evident that there were few variations in the size of livestock supplied to different regions of London. There is limited evidence for the selection of larger animals for the city markets from the hinterland in some phases, although more data are required to explore this. Two sites in the Northern Suburbs (STE95 and SRP98) were being supplied with larger (male) cattle and sheep. It is possible that this larger morph simply represents a variety/deme local to the northern suburbs, or the northern suburbs did not acquire cattle from other parts of the capital and so missed out on some particularly morphologically small demes, hence the difference in means. Given the practice of bone-working at these locations, however, a more satisfying explanation is that larger-boned animals were preferentially selected: the metapodials of these animals would have provided a larger surface area for working on lathes in the production of gaming pieces, knife handles and needles, for example.

Going beyond the identification of temporal variation, it is necessary to understand the socio-economic context and the mechanisms by which size changes occurred. In the 13th and early 14th century, increasing population numbers led to an expansion of arable farming, forcing sheep and cattle to graze on marginal lands and limiting the opportunities for dedicated meadows. Within this context it is possible that the largest and strongest bull calves were castrated to provide the best animals for traction. As Armitage (1980) observes, the unintended consequence of this negative breeding strategy would have been the selection of

smaller animals for breeding stock, thus perpetuating smaller sized cattle. Alternatively, no selection policy regarding which animals were left entire may have been practiced: Thomas Tusser (1610) advocates gelding rams and bulls as soon as their testicles descended before any judgement could be made about the quality of the animal. The size of livestock may have also been suppressed by inadequate nutrition, particularly over winter and, for cattle and sheep, the lack of opportunities for controlling breeding within the open-field system (Armitage, 1980, Russell, 1986). Stable isotope evidence certainly indicates that prior to the 14th century pigs were managed extensively in woodlands, wastes, marshlands, and fields, and little control was exerted over food intake and breeding (Hamilton and Thomas, 2012).

It is evident from the London dataset that increases in livestock size were occurring for cattle and sheep from the early 14th century: this is earlier than any previously documented instance of livestock size increase in the medieval period – Armitage (1980) and Thomas (2005a, Thomas, 2005b) had previously established this as the later 14th century. The fact that only cattle and sheep witness this size change is noteworthy, given the fact that there were major outbreaks of disease affecting these animals in the first quarter of the 14th century. Sheep murrain (an unspecified infectious disease) was epidemic between 1314 and 1316, while a panzootic in cattle (probably rinderpest) was widespread between 1319 and 1322 (Jordan, 1996, Newfield, 2009). The scale of mortality was astonishing; manorial accounts indicate that around 62 per cent of cattle died of pestilence in England and Wales in the period 1319–20 (Slavin, 2011). Given the timing of the size increases, and the fact that only cattle and sheep are affected, it is possible that they reflect re-stocking policies. Deliberate selective breeding from larger ‘imported’ animals was probably not the cause: there is no zooarchaeological evidence for large livestock elsewhere in England and Wales in this period and while the international movement of livestock occurred sporadically (Trow-Smith, 1957), large-scale intra- and trans-national cattle trade did not commence until the late 15th century (Slavin, 2011). A temporary relative increase in mean size may have occurred in the archaeological (death) assemblage, because of relatively higher slaughter rates of male cattle in the aftermath of the pestilence; indeed, a shift away from females to males is hinted at in zooarchaeological record (Figure 10). This might be explained by the fact that mortality of cows was greater than it was for bulls and castrates respectively (Slavin, 2011) and thus there may have been greater imperative to keep breeding animals from slaughter. Alternatively, the larger size of cattle and sheep may reflect the actions of natural selection. Three consecutive failed crop harvests in the period 1315–1317 occurred as a consequence of torrential rainfall,

and constituted a major contributing factor to a human famine that resulted in the death of 10-15% of the European population (Jordan, 1996). Poor crop yields and spoiled hay also affected the ability of farmers to adequately feed livestock over winter (Slavin, 2011). It is entirely conceivable that smaller, weaker animals were more susceptible to malnutrition and ultimately mortality, while the larger, healthier animals survived to perpetuate their genes.

Further episodes of size increase occurred in sheep and domestic hen in the 15th century; such changes might be explained by the altered tenurial and agricultural landscape in the wake of the Black Death (Thomas, 2005a, Thomas, 2005b). Following the plague, the demand to feed an expanding population dissipated and the market in grain crashed; animal husbandry thus became a viable alternative since it was land extensive but less labour intensive. Alongside the widespread conversion of ploughed land to pasture, which relieved the pressure on grazing land in some areas (Dodds, 2008, Dyer, 1981, Stone, 2005), changes in landholding arrangements occurred. The practice of direct management of estates was increasingly replaced by leasing for cash rents, as landlords sought to minimise economic loss. One consequence, coupled with increasing wage demands in this period, was a downward social distribution of access to land (Dyer, 1981); the size of land-holdings also increased as parcels of vacant land were purchased and amalgamated. In the case of domestic hen husbandry, there was a noticeable shift of the entire sector from the demesne to the 'peasantry' (Slavin, 2009). These changes may have led to increased livestock size in a number of ways.

Changing agricultural emphasis might have altered the balance of sexes within the herds/flocks. This certainly seems to be the case with domestic hens (Figure 13), where there was an increase in the relative abundance of males (presumably for meat), although the primary emphasis remained on egg production. The rise in caponisation observed on manors in eastern England in the wake of the Black Death (Slavin, 2009) is consistent with this trend. For cattle, too there is tentative evidence for a shift away from cows to castrates (Figure 10), but no such changes are evident for sheep. Improvements in nutritional plane may have been influential, however, and allowed animals to reach their genotypic potential following a shift from stocking on marginal or over-grazed pastures, with limited capacity for meadows, to prime pasture. The reduction in pressure on harvested crops following the population crash would have also increased the possibility of supplementing animal diet over winter with surplus crops. Another influential factor that might have increased livestock size in this period is the enclosure of common pasture, which began in the 14th century in some regions

(e.g. Dyer, 1981) and would have enabled greater control over food intake and breeding to be exerted. Zooarchaeological and stable isotope evidence from Dudley Castle, West Midlands, certainly indicates a switch towards the enclosed management of pigs in this period (Hamilton and Thomas, 2012). Increased herd/flock sizes would have also afforded greater opportunity for the ‘improvement’ of livestock; greater variability is expressed in larger populations, thus providing more choice for the selection of breeding animals and enabling a specific group of animals to be marked out for breeding (Armitage, 1980, Russell, 1986). Documentary sources certainly indicate that individual livestock farmers in some regions were able to increase the amount of reserved pasture and graze more animals in the wake of the Black Death (Stern, 2000, Stone, 2005, Thirsk, 1997). Furthermore, since the new landowners were leasing for cash rent, they would have had greater incentive for enhancing stock profitability: larger animals would have meant more meat and, in the case of sheep, larger fleeces. As Dyer (1997) notes, “in some circumstances lords could have acted as a drag on change”; Stone (2005) also comments that “many of the farm managers that great landlords secured during this period [the late 14th and early 15th century] were considerably less flexible and less skilled”. In contrast, peasants who became landowners in this period are likely to have been in “intimate contact” with the animals and better able to take “technological initiatives” (Dyer, 1997) and thus proactively respond to the prevailing conditions (Stone, 2005). Such arguments require the existence of some knowledge amongst contemporary breeders concerning the inheritance of body size, however.

Prior to the widespread adoption of the printing press in England in the 16th century, contemporary knowledge concerning livestock breeding are difficult to discern. It is possible that printed works consolidated pre-existing knowledge which circulated as part of an oral tradition, supplemented with rediscovered classical scholarship (e.g. Mascall, 1587, Choysselat, 1580 [Neville, 1951]). However, it is also clear that innovatory advice concerning animal husbandry and agriculture more broadly were set forth within such texts, particularly by the latter half of the 17th century (Blith, 1653, Weston, 1654, Worlidge, 1698). While the principles of heredity in the early modern period were not well understood, breeding from larger animals was frequently advocated, and increasing awareness is shown regarding the importance of selecting breeding stock carefully. In the 1598 edition of Anthony Fitzherbert’s *Boke of Hubsandry* (originally published in 1534), there exists a collection of notes written by the anonymous I.R., which includes the following advice: “when you chuse sheepe, elect them big-boand and well-woolld”, while cows should be “so bigge as bigge may be” (Skeat,

1882). Gervase Markham, writing of sheep in 1648 similarly recommends to “chose the biggest boned, with the best wooll” explaining that “these sheep besides the bearing of the best burthen, are always the best Butchers ware, and go soonest away in the Market” (Markham, 1648). Echoing the advice of Prudent Choyselat in 1580 (Neville, 1951), Markham advises that cockerels should present a “large and well sized body, long from head to the rump and thick in the garth”, while the “biggest and largest” hens are the best (Markham, 1648). Such evidence supports the view of Russell (1986) and Fussell (1929) that before the 18th century emphasis was placed on simple morphological characters, most especially size, rather than other productive attributes which required detailed record keeping (e.g. milk yields and fertility). Further evidence that some early modern livestock owners were aware of the value of selective breeding, is revealed by the acclaim paid to certain foreign breeds. John Worlidge, explained that: “the *Dutch-Sheep* are the largest of all, being much bigger than I have seen in *England*...it may doubtless be of very good advantage to obtain of those kinds, and also of Spanish-Sheep, that bear such fine Fleeces” (Worlidge, 1698); similar sentiments were expressed by Samuel Hartlib (1655) and John Beale (1674).

From 1500 until the late 18th century, a rising population, increased disposable income and urban expansion fostered a developing market of animals and animal products (especially meat, dairy and fleeces) which in turn incentivised stratification, specialisation and innovation in livestock husbandry (Russell, 1986, Trow-Smith, 1957). Certainly, much greater attention in contemporary agricultural manuals concerning animal feeding regimes and care is evident in this period (Curth, 2010, Rixson, 2000), while the enclosure movement and the development of meadows rapidly gained pace, especially following the dissolution of the monasteries. From the late 16th/early 17th century there is growing documentary evidence for the importation of foreign livestock (Thirsk, 1967, Trow-Smith, 1957, Trow-Smith, 1959), such as the long-legged, short horned Dutch cattle described by Mortimer (1708). The development of the city of London must certainly be viewed as a major contributing factor, since it witnessed “massive and sustained expansion” in the early modern period (Harding, 1990) and expanded well beyond the city walls. In the fifty year period between 1550 and 1600 alone, the population is thought to have quadrupled (Schofield, 2011). To provide some sense of scale of this expansion and its effect on animal procurement, in 1725, the consumption of meat in the city was estimated at: “98,000 beeves, 60,000 calves, 70,000 sheep and lambs, 187,000 swine, 52,000 sucking pigs” (Besant, 1902); by 1793 the number

of cattle and sheep passing through the Smithfield market alone had risen to 116,488 and 729,810 respectively (Trow-Smith, 1959).

This drive towards the production of larger stock is manifest in the zooarchaeological evidence in this and previous studies. Decreasing slaughter ages also attest to the presence of faster maturing animals and the increasing change in focus from secondary to primary products (Albarella, 1997b). This is partially evident in the sheep dataset, through an increased emphasis on male sheep in the period 1600-1725 (Figure 12) testifying to a gradual shift away from milk and wool production (which necessitated a greater abundance of ewes and wethers), towards the supply of mutton and lamb to urban markets (for which rams and wethers were better suited because of their larger carcass weight) (Dobney, et al., 1996, Maltby, 1979, Thomas, 2005a). This phenomenon is also historically-attested, Thirsk (1985) notes that the ban on wool exports for 150 years from 1614 led to a situation where farmers who persisted in keeping sheep began to concentrate their efforts on meat rather than wool production; by the first half of the 18th century sales of mutton had increased by over 50% (Chartres, 1985).

By the end of the medieval period different morphotypes of animal are also apparent. For example, there is a switch from cattle with 'small' and 'short' horns in the 13th-15th centuries to cattle with 'medium' and 'long' horns from the mid-16th century (Figure 6). A similar pattern was observed by Armitage (1980), although in this study the transition occurred from the late 14th-early 15th century. While different regional types of sheep were recognised from the medieval period (Trow-Smith, 1957), by the 17th century sheep of very different conformation are apparent in the archaeological record for London (Figure 12), supporting the opinion of early modern writers, such as John Worlidge who noted: "there are of several kinds, as to their Proportion; some are very small, others larger" (Worlidge, 1698).

From the 18th century the focus of breeding had shifted away from a desire to increase bulk size towards the selection of other productive attributes, such as milk yield, or the balance of meat, fat and bone (Russell, 1986, Trow-Smith, 1959). These changes are best viewed within the context of the ethic of improvement (Tarlow 2007), in which aesthetic as well as productive characters were deliberately selected. It is notable that cattle, pig, and sheep in this study did not increase in size after the early 18th century. Although a small sample size may be partially responsible, this corresponds with the available documentary evidence which

suggests no significant change in cattle and sheep size from the late 17th century until the third quarter of the 18th century (Fussell, 1929, Russell, 1986). For sheep, however, there is certainly evidence for further increases in size in the 18th century, as there has been at other sites (O'Connor, 1995, Vann and Grimm, 2010) and accords with documentary evidence for carcass weight and fleece yield increases in the period (Fussell and Goodman 1930; Russell, 1986).

5 Conclusions

This study has revealed multiple episodes of size change, supporting the view that increases in livestock size in the late medieval and early modern period occurred as part of a long-term and gradual process. The earliest evidence for size change in cattle and sheep occurs in the early 14th century and may reflect the impact of murrain in the first half of that century. Subsequent size increases in livestock size may have occurred as a consequence of the changing agricultural emphasis and/or innovatory practice in the wake of the Black Death and the increasing commercialisation of animal farming, as the food requirements of an expanding London grew. It is certainly evident through documentary evidence that from the later 17th century, there was a growing understanding of the principles of heredity and more careful selection of breeding stock was advocated by some authors; however the emphasis appears to have been on crude size. Unfortunately, the absence of dental evidence for the London sites makes it impossible to disentangle whether the observed size changes were a consequence of environmental or genetic factors (e.g. through selective breeding or the introduction of new bloodlines); although there is evidence elsewhere in England that this may too have commenced as early as the later 14th century (Thomas, 2005a, Thomas, 2005b). Clearly, the collection and publication of such data is a future research priority. Only for sheep is there evidence for further episodes of size increase in the 18th century. It is speculated that the absence of size increase for cattle, pig and domestic hen in this period reflects the changing emphasis in breeding practice, away from bulk size towards the improvement of other productive and aesthetic attributes; additional data are required to investigate this phenomenon.

6 Acknowledgments

We gratefully acknowledge the City of London Archaeological Trust for funding this research and Museum of London Archaeology (MOLA) for granting permission to use their data. Particular thanks must go David Bowsher, Natasha Powers and all the zooarchaeologists

of MOLA past and present who recorded the data utilised in this study. We would also like to thank the three anonymous reviewers, Brooklynne “Tyr” Fothergill, Rebecca Gordon, Sheila Hamilton-Dyer, Naomi Sykes and Eric Tourigny.

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Table 1: phasing used in this study.

Table 2: list of post-cranial bone measurements used in this study together with the measurements from the standards used for log scaling. The following reference skeletons were chosen as standards: Chillingham bull, University of Leicester reference collection R625; Soay ewe, University of Leicester reference collection R159; Feral Australian sow described in Legge (2009) No.LL1; and a Warren-Ranger hybrid hen, University of Leicester reference collection R615. Measurement codes follow von den Driesch (1976). Key: † Bd for pigs; *metacarpal IV for pigs; ** metatarsal III for pigs.

Table 3: frequency of post-cranial bone and horncore measurements (in parentheses) by taxon and phase. The total number of measured bones analysed in Phase A and B is greater than the sum of the sub-phases, because some assemblages could not be accurately dated.

Table 4: statistical comparison of log-scaled measurements (all post-cranial bones combined) by phase between sites within the city and sites in Greater London. Shaded boxes indicate statistically-significant differences.

Table 5: univariate analysis of log-scaled cattle post-cranial bone measurements. The phase B2 dump of cattle metapodials from STE95 has been excluded.

Table 6: Mann-Witney U-test of log-scaled cattle post-cranial bone measurements. Shaded boxes indicate statistically-significant differences. The phase B2 dump of cattle metapodials from STE95 has been excluded.

Table 7: univariate analysis of log-scaled sheep post-cranial bone measurements.

Table 8: Mann-Witney U-test of log-scaled sheep post-cranial bone measurements. Shaded boxes indicate statistically-significant differences.

Table 9: univariate analysis of log-scaled pig post-cranial bone measurements.

Table 10: Mann-Witney U-test of log-scaled pig post-cranial bone measurements (all measurements combined). Shaded boxes indicate statistically-significant differences.

Table 11: univariate analysis of log-scaled domestic hen post-cranial bone measurements.

Table 12: Mann-Witney U-test of log-scaled domestic hen post-cranial bone measurements.

Shaded boxes indicate statistically-significant differences.

Table 13: coefficients of variation for sheep metacarpal distal breadth measurements. A value greater than six is considered indicative of the presence of two or more breeds with different shapes (Popkin et al. 2012).

| Phase | Dates |
|-------|-----------|
| A | 1220-1350 |
| B | 1340-1500 |
| C | 1450-1600 |
| D | 1550-1650 |
| E | 1600-1700 |
| F | 1650-1725 |
| G | 1700-1800 |
| H | 1800-1900 |

| Element | Measurement | Cattle | Sheep | Pig | Chicken |
|----------------------------------|-------------|--------|-------|-------|---------|
| Humerus | GL | 301.0 | 120.2 | 166.0 | 74.0 |
| | SC | - | - | - | 6.6 |
| | BT† | 75.5 | 23.7 | 38.7 | - |
| Coracoid | GL | - | - | - | 57.3 |
| | BF | - | - | - | 13.5 |
| Radius | GL | 265.0 | 129.8 | - | - |
| | Bd | 72.2 | 23.8 | - | - |
| Ulna | GL | - | - | - | 75 |
| | SC | - | - | - | 3.9 |
| | Did | - | - | - | 10.1 |
| Femur | GL | 362.0 | 147.0 | 186.5 | 85.2 |
| | SC | - | - | - | 7.9 |
| | DC/Dp | 46.5 | 16.5 | - | 12.4 |
| | Bd | 103.0 | 30.8 | 42.1 | - |
| Tibia/tibiotarsus | GL | 337.0 | 178.0 | 169 | 116.4 |
| | SC | - | - | - | 7.3 |
| | Dp | - | - | - | 22.2 |
| | Bd | 63.9 | 21.3 | 27.5 | 13.0 |
| | Dd | 49.7 | 16.8 | 24.5 | - |
| Astragalus | GLI | 63.8 | 23.8 | 37.9 | - |
| | Bd | 44.9 | 15.8 | 22.8 | - |
| | DI | 35.3 | 13.5 | - | - |
| Calcaneum | GL | 138.2 | 48.3 | 68.8 | - |
| Metacarpal* | GL | 185.0 | 109.6 | 65.3 | - |
| | SD | 36.6 | 11.9 | - | - |
| | Bp | - | - | 14.1 | - |
| | Bd | 64.2 | 20.8 | - | - |
| Metatarsal**/ tarsometatarsus | GL | 216.0 | 119.9 | 70.0 | 76.9 |
| | SD/SC | 31.5 | 9.6 | - | 7.0 |
| | Bp | - | - | 14.0 | - |
| | Bd | 59.2 | 20.1 | - | - |

| | A (1220-1350) | A1 (1220-1300) | A2 (1230-1350) | B (1340-1500) | B1 (1340-1450) | B2 (1400-1500) | C (1450-1600) | D (1550-1650) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) | TOTAL |
|--------------|---------------|----------------|----------------|---------------|----------------|----------------|---------------|---------------|---------------|---------------|---------------|---------------|-------|
| Cattle | 193 (94) | 92 (37) | 102 (57) | 511 (34) | 58 (4) | 407 (27) | 98 (0) | 202 (307) | 122 (59) | 135 (2415) | 84 (4) | 21 (21) | 4300 |
| Sheep | 236 | 97 | 136 | 310 | 156 | 116 | 153 | 356 | 303 | 139 | 335 | 119 | 1951 |
| Pig | 29 | 11 | 18 | 21 | 14 | 6 | 10 | 28 | 9 | 4 | 18 | 2 | 121 |
| Domestic hen | 323 | 178 | 145 | 493 | 173 | 240 | 255 | 214 | 61 | 38 | 99 | 111 | 1594 |
| Total | 875 | 415 | 458 | 1369 | 405 | 796 | 516 | 1107 | 554 | 2731 | 540 | 274 | 7966 |

| | | A (1220-1350) | B (1340-1500) | C (1450-1600) | D (1550-1650) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) |
|-----------------|---|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| cattle | U | 1629 | 237 | 369.5 | 470.5 | 172 | - | 146 | 24 |
| | P | 0.0185 | 0.0000 | 0.7066 | 0.0199 | 0.0488 | - | 0.0161 | 0.3295 |
| sheep | U | 4286 | 2278 | 419.5 | 2316 | 172 | - | 718.5 | 567 |
| | P | 0.1171 | 0.0030 | 0.0753 | 0.8353 | 0.0635 | - | 0.6355 | 0.8455 |
| domestic hen | U | 132 | 4863 | 2262 | 178.5 | - | - | - | 190.5 |
| | P | 0.4623 | 0.6372 | 0.0243 | 0.7045 | - | - | - | 0.0042 |

| | | A (1220-1300) | A1 (1220-1300) | A2 (1230-1350) | B (1400-1500) | B1 (1340-1450) | B2 (1400-1500) | C (1450-1600) | D (1550-1650) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) |
|---------|------------|---------------|----------------|----------------|---------------|----------------|----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Length | N | 56 | 29 | 27 | 38 | 10 | 11 | 28 | 77 | 4 | 5 | 25 | 7 |
| | Min | -0.12 | -0.12 | -0.09 | -0.11 | -0.11 | -0.02 | -0.06 | -0.06 | 0 | -0.04 | -0.05 | -0.05 |
| | Max | 0.04 | 0 | 0.04 | 0.07 | 0.02 | 0.07 | 0.1 | 0.07 | 0.09 | 0.1 | 0.1 | 0.11 |
| | Mean | -0.0282 | -0.0383 | -0.0174 | 0.0003 | -0.0200 | 0.0100 | 0.0089 | 0.0143 | 0.0475 | 0.0120 | 0.0304 | 0.0071 |
| | Stand. dev | 0.0321 | 0.0292 | 0.0322 | 0.0380 | 0.0362 | 0.0276 | 0.0354 | 0.0264 | 0.0377 | 0.0642 | 0.0426 | 0.0525 |
| Breadth | N | 112 | 48 | 65 | 101 | 41 | 35 | 58 | 113 | 112 | 130 | 56 | 12 |
| | Min | -0.16 | -0.15 | -0.16 | -0.13 | -0.13 | -0.13 | -0.12 | -0.19 | -0.1 | -0.13 | -0.06 | -0.11 |
| | Max | 0.07 | 0.02 | 0.07 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 | 0.09 | 0.14 | 0.14 | 0.07 |
| | Mean | -0.0657 | -0.0748 | -0.0582 | -0.0430 | -0.0502 | -0.0477 | -0.0317 | -0.0191 | 0.0059 | 0.0205 | 0.0171 | -0.0083 |
| | Stand. dev | 0.0450 | 0.0392 | 0.0480 | 0.0458 | 0.0439 | 0.0454 | 0.0441 | 0.0414 | 0.0435 | 0.0437 | 0.0507 | 0.0685 |
| Depth | N | 25 | 15 | 10 | 20 | 7 | 8 | 12 | 12 | 6 | - | 3 | 2 |
| | Min | -0.12 | -0.12 | -0.08 | -0.12 | -0.08 | -0.09 | -0.08 | -0.08 | -0.03 | - | 0.03 | 0.05 |
| | Max | 0.03 | 0.01 | 0.03 | 0.03 | 0.03 | 0 | 0.09 | 0.03 | 0.04 | - | 0.07 | 0.06 |
| | Mean | -0.0552 | -0.0680 | -0.0360 | -0.0455 | -0.0371 | -0.0463 | -0.0083 | -0.0200 | 0.0083 | - | 0.0433 | - |
| | Stand. dev | 0.0389 | 0.0373 | 0.0344 | 0.0397 | 0.0431 | 0.0320 | 0.0490 | 0.0388 | 0.0232 | - | 0.0231 | - |
| All | N | 193 | 92 | 102 | 54 | 58 | 54 | 98 | 202 | 122 | 135 | 84 | 21 |
| | Min | -0.16 | -0.15 | -0.16 | -0.13 | -0.13 | -0.13 | -0.12 | -0.19 | -0.1 | -0.13 | -0.06 | -0.11 |
| | Max | 0.07 | 0.02 | 0.07 | 0.07 | 0.05 | 0.07 | 0.1 | 0.07 | 0.09 | 0.14 | 0.14 | 0.11 |
| | Mean | -0.0535 | -0.0622 | -0.0452 | -0.0357 | -0.0434 | -0.0357 | -0.0172 | -0.0064 | 0.0074 | 0.0202 | 0.0220 | 0.0029 |
| | Stand. dev | 0.0439 | 0.0393 | 0.0464 | 0.0463 | 0.0435 | 0.0463 | 0.0458 | 0.0396 | 0.0430 | 0.0444 | 0.0479 | 0.0613 |

| | | A (1220-1350) - B (1340-1500) | B (1340-1500) - C (1450-1600) | C (1450-1600) - D (1550-1600) | D (1550-1600) - E (1600-1700) | E (1600-1700) - F (1650-1725) | F (1650-1725) - G (1700-1800) | G (1700-1800) - H (1800-1900) | A1 (1220-1300) - A2 (1230-1350) | A2 (1230-1350) - B1 (1230-1450) | B1 (1340-1450) - B2 (1400-1500) |
|---------|---|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|------------------------------------|------------------------------------|------------------------------------|
| Length | U | 531 | 475 | 979 | 69 | 6.5 | 47 | 59 | 257 | 128.5 | 27 |
| | P | 0.0002 | 0.4612 | 0.4717 | 0.0630 | 0.4587 | 0.4023 | 0.2003 | 0.0268 | 0.8357 | 0.0509 |
| Breadth | U | 4054 | 2502 | 2737 | 4380 | 5889 | 3439 | 270.5 | 1269 | 1202 | 674 |
| | P | 0.0004 | 0.1260 | 0.0771 | 6.270x10 ⁻⁵ | 0.0101 | 0.5492 | 0.2945 | 0.0900 | 0.3978 | 0.6531 |
| Depth | U | 211.5 | 66.5 | 64 | 21 | - | - | - | 36 | 32.5 | 25 |
| | P | 0.3828 | 0.0384 | 0.6635 | 0.1718 | - | - | - | 0.0316 | 0.8438 | 0.7713 |

| | | A (1220-1300) | A1 (1220-1300) | A2 (1230-1350) | B (1340-1500) | B1 (1340-1450) | B2 (1400-1500) | C (1450-1600) | D (1550-1650) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) |
|---------|------------|---------------|----------------|----------------|---------------|----------------|----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Length | N | 70 | 30 | 37 | 82 | 30 | 38 | 42 | 83 | 51 | 41 | 82 | 37 |
| | Min | -0.06 | -0.02 | -0.06 | -0.02 | -0.02 | -0.02 | -0.02 | -0.03 | -0.03 | -0.04 | 0 | -0.06 |
| | Max | 0.13 | 0.09 | 0.13 | 0.18 | 0.18 | 0.08 | 0.19 | 0.12 | 0.14 | 0.13 | 0.17 | 0.16 |
| | Mean | 0.0274 | 0.0397 | 0.0181 | 0.0362 | 0.0353 | 0.0395 | 0.0576 | 0.0618 | 0.0484 | 0.0432 | 0.0830 | 0.0678 |
| | Stand. dev | 0.0326 | 0.0270 | 0.0345 | 0.0322 | 0.0406 | 0.0266 | 0.0415 | 0.0305 | 0.0391 | 0.0422 | 0.0437 | 0.0426 |
| Breadth | N | 136 | 51 | 85 | 192 | 71 | 99 | 93 | 240 | 232 | 88 | 219 | 65 |
| | Min | -0.01 | -0.01 | 0 | 0 | 0 | 0.02 | 0 | -0.12 | 0.01 | 0.03 | 0.03 | -0.03 |
| | Max | 0.15 | 0.15 | 0.1 | 0.17 | 0.17 | 0.14 | 0.19 | 0.16 | 0.18 | 0.2 | 0.2 | 0.2 |
| | Mean | 0.0543 | 0.0553 | 0.0538 | 0.0673 | 0.0606 | 0.0721 | 0.0811 | 0.0895 | 0.1016 | 0.1034 | 0.1177 | 0.1060 |
| | Stand. dev | 0.0258 | 0.0286 | 0.0242 | 0.0264 | 0.0293 | 0.0240 | 0.0284 | 0.0293 | 0.0335 | 0.0336 | 0.0370 | 0.0441 |
| Depth | N | 30 | 16 | 14 | 36 | 15 | 19 | 18 | 33 | 20 | 10 | 34 | 17 |
| | Min | 0 | 0 | 0.03 | 0.01 | 0.01 | 0.01 | 0.04 | 0.04 | 0.01 | 0.03 | 0.04 | 0.04 |
| | Max | 0.11 | 0.11 | 0.09 | 0.11 | 0.1 | 0.11 | 0.17 | 0.16 | 0.18 | 0.13 | 0.18 | 0.19 |
| | Mean | 0.0580 | 0.0525 | 0.0643 | 0.0619 | 0.0560 | 0.0674 | 0.0761 | 0.0882 | 0.1120 | 0.0960 | 0.1162 | 0.1271 |
| | Stand. dev | 0.0237 | 0.0274 | 0.0174 | 0.0267 | 0.0295 | 0.0254 | 0.0305 | 0.0306 | 0.0424 | 0.0306 | 0.0352 | 0.0450 |
| All | N | 236 | 97 | 136 | 310 | 116 | 156 | 153 | 356 | 303 | 139 | 335 | 119 |
| | Min | -0.06 | -0.02 | -0.06 | -0.02 | -0.02 | -0.02 | -0.02 | -0.12 | -0.03 | -0.04 | 0 | -0.06 |
| | Max | 0.15 | 0.15 | 0.13 | 0.18 | 0.18 | 0.14 | 0.19 | 0.16 | 0.18 | 0.2 | 0.2 | 0.2 |
| | Mean | 0.0468 | 0.0500 | 0.0451 | 0.0585 | 0.0534 | 0.0636 | 0.0741 | 0.0829 | 0.0933 | 0.0851 | 0.1091 | 0.0971 |
| | Stand. dev | 0.0304 | 0.0285 | 0.0315 | 0.0311 | 0.0341 | 0.0283 | 0.0341 | 0.0318 | 0.0405 | 0.0451 | 0.0412 | 0.0482 |

| | | A (1220-1350)- B (1340-1500) | B (1340-1500) - C (1450-1600) | C (1450-1600) - D (1550-1600) | D (1550-1600) - E (1600-1700) | E (1600-1700) - F (1650-1725) | F (1650-1725) - G (1700-1800) | G (1700-1800) - H (1800-1900) | A1 (1220-1300) - A2 (1230-1350) | A2 (1230-1350) - B1 (1230-1450) | B1 (1340-1450) - B2 (1400-1500) |
|---------|---|---------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|------------------------------------|------------------------------------|------------------------------------|
| Length | U | 2441 | 1167 | 1487 | 1632 | 983.5 | 896 | 1239 | 307.5 | 410.5 | 481.5 |
| | P | 0.1109 | 0.0032 | 0.1785 | 0.0259 | 0.6279 | 2.46x10 ⁻⁵ | 0.1093 | 0.0017 | 0.0676 | 0.2744 |
| Breadth | U | 9589 | 6382 | 8771 | 2.15x10 ⁴ | 1.01x10 ⁴ | 7455 | 5980 | 2140 | 2669 | 2650 |
| | P | 3.66x10 ⁻⁵ | 8.48x10 ⁻⁵ | 0.0023 | 1.76x10 ⁻⁵ | 0.9145 | 0.0019 | 0.0498 | 0.9009 | 0.2116 | 0.0059 |
| Depth | U | 483.5 | 254 | 226 | 197 | 72 | 116 | 228 | 75.5 | 88 | 108.5 |
| | P | 0.4663 | 0.1968 | 0.1609 | 0.0144 | 0.2233 | 0.1317 | 0.2249 | 0.1289 | 0.4662 | 0.2391 |

| | | A (1220-1350) | B (1340-1500) | C (1450-1600) | D (1550-1650) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) |
|---------|------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Length | N | 15 | 4 | 4 | 11 | 2 | 2 | 2 | 3 |
| | Min | -0.01 | 0.05 | 0.02 | 0.05 | 0.11 | 0.07 | 0.14 | 0.07 |
| | Max | 0.11 | 0.15 | 0.12 | 0.17 | 0.11 | 0.14 | 0.15 | 0.11 |
| | Mean | 0.0353 | 0.0825 | 0.0875 | 0.1082 | - | - | - | 0.0900 |
| | Stand. dev | 0.0346 | 0.0457 | 0.0472 | 0.0368 | - | - | - | - |
| Breadth | N | 11 | 14 | 5 | 14 | 5 | 1 | 8 | 2 |
| | Min | -0.04 | -0.01 | -0.01 | -0.05 | 0.02 | 0.11 | -0.02 | 0 |
| | Max | 0.16 | 0.07 | 0.11 | 0.11 | 0.12 | 0.11 | 0.17 | 0.08 |
| | Mean | 0.0136 | 0.0300 | 0.0400 | 0.0343 | 0.0820 | - | 0.0613 | - |
| | Stand. dev | 0.0599 | 0.0245 | 0.0500 | 0.0427 | 0.0449 | - | 0.0673 | - |
| Depth | N | 3 | 3 | 1 | 3 | 2 | 1 | 5 | - |
| | Min | 0.02 | 0.00 | 0.06 | 0.03 | 0.12 | 0.09 | 0.04 | - |
| | Max | 0.04 | 0.09 | 0.06 | 0.11 | 0.12 | 0.09 | 0.13 | - |
| | Mean | 0.0300 | 0.0333 | - | 0.0633 | - | - | 0.0680 | - |
| | Stand. dev | - | - | - | - | - | - | 0.0383 | - |
| All | N | 29 | 21 | 10 | 28 | 9 | 4 | 18 | 2 |
| | Min | -0.04 | -0.01 | -0.01 | -0.05 | 0.02 | 0.07 | -0.02 | 0 |
| | Max | 0.16 | 0.15 | 0.12 | 0.17 | 0.12 | 0.14 | 0.17 | 0.11 |
| | Mean | 0.0266 | 0.0405 | 0.0610 | 0.0664 | 0.0967 | 0.1025 | 0.0761 | - |
| | Stand. dev | 0.0447 | 0.0372 | 0.0491 | 0.0525 | 0.0364 | 0.0299 | 0.0541 | - |

| | A (1220-1350)- B (1340-1500) | B (1340-1500) - C (1450-1600) | C (1450-1600) - D (1550-1600) | D (1550-1600) - E (1600-1700) | E (1600-1700) - F (1650-1725) | F (1650-1725) - G (1700-1800) | G (1700-1800) - H (1800-1900) | A+B (1220-1500) - C+D (1450-1600) | C+D (1450-1600) - E+F (1600-1725) | E+F (1600-1725) - G+H (1700-1900) |
|---|---------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| U | 237 | 77.5 | 134 | 74.5 | 17 | 20.5 | 15 | 580 | 141.5 | 93 |
| P | 0.1861 | 0.2520 | 0.8549 | 0.0697 | 0.9373 | 0.3664 | 0.7516 | 0.0018 | 0.0226 | 0.1773 |

| | | A (1220-1350) | A1 (1220-1300) | A2 (1230-1350) | B (1340-1500) | B1 (1340-1450) | B2 (1400-1500) | C (1450-1600) | D (1550-1650) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) |
|---------|------------|---------------|----------------|----------------|---------------|----------------|----------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Length | N | 115 | 53 | 62 | 244 | 88.00 | 124 | 107 | 102 | 25 | 15 | 49 | 48 |
| | Min | -0.14 | -0.09 | -0.14 | -0.17 | -0.17 | -0.1 | -0.11 | -0.11 | -0.06 | -0.08 | -0.08 | -0.07 |
| | Max | 0.11 | 0.04 | 0.11 | 0.16 | 0.11 | 0.16 | 0.13 | 0.15 | 0.1 | 0.08 | 0.1 | 0.09 |
| | Mean | -0.0460 | -0.0481 | -0.0442 | -0.0051 | -0.0344 | 0.0160 | 0.0020 | 0.0043 | -0.0112 | -0.0187 | -0.0188 | -0.0067 |
| | Stand. dev | 0.0399 | 0.0306 | 0.0466 | 0.0603 | 0.0521 | 0.0588 | 0.0530 | 0.0529 | 0.0417 | 0.0396 | 0.0382 | 0.0385 |
| Breadth | N | 163 | 96 | 67 | 195 | 67 | 95 | 106 | 89 | 28 | 16 | 36 | 46 |
| | Min | -0.17 | -0.17 | -0.15 | -0.2 | -0.2 | -0.11 | -0.15 | -0.12 | -0.1 | -0.11 | -0.08 | -0.1 |
| | Max | 0.12 | 0.11 | 0.12 | 0.19 | 0.1 | 0.19 | 0.16 | 0.11 | 0.11 | 0.08 | 0.11 | 0.11 |
| | Mean | -0.0479 | -0.0440 | -0.0534 | -0.0134 | -0.0460 | 0.0125 | 0.0009 | 0.0015 | -0.0004 | -0.0038 | -0.0075 | 0.0011 |
| | Stand. dev | 0.0575 | 0.0569 | 0.0583 | 0.0709 | 0.0667 | 0.0616 | 0.0689 | 0.0576 | 0.0590 | 0.0630 | 0.0554 | 0.0516 |
| Depth | N | 45 | 29 | 16 | 54 | 18 | 21 | 42 | 23 | 8 | 7 | 14 | 17 |
| | Min | -0.17 | -0.14 | -0.17 | -0.19 | -0.16 | -0.19 | -0.18 | -0.11 | -0.1 | -0.12 | -0.1 | -0.08 |
| | Max | 0.06 | 0.04 | 0.06 | 0.12 | 0.07 | 0.12 | 0.06 | 0.08 | 0.06 | 0.1 | 0.04 | 0.13 |
| | Mean | -0.0784 | -0.0731 | -0.0881 | -0.0550 | -0.0711 | -0.0276 | -0.0295 | -0.0283 | -0.0300 | -0.0386 | -0.0379 | -0.0188 |
| | Stand. dev | 0.0532 | 0.0524 | 0.0549 | 0.0733 | 0.0686 | 0.0859 | 0.0655 | 0.0425 | 0.0504 | 0.0834 | 0.0442 | 0.0593 |
| All | N | 323 | 178 | 145 | 493 | 173 | 240 | 255 | 214 | 61 | 38 | 99 | 111 |
| | Min | -0.17 | -0.17 | -0.17 | -0.2 | -0.2 | -0.19 | -0.18 | -0.12 | -0.1 | -0.12 | -0.1 | -0.1 |
| | Max | 0.12 | 0.11 | 0.12 | 0.19 | 0.11 | 0.19 | 0.16 | 0.15 | 0.11 | 0.1 | 0.11 | 0.13 |
| | Mean | -0.0515 | -0.0499 | -0.0533 | -0.0138 | -0.0427 | 0.0108 | -0.0036 | -0.0004 | -0.0087 | -0.0161 | -0.0174 | -0.0053 |
| | Stand. dev | 0.0522 | 0.0505 | 0.0544 | 0.0677 | 0.0605 | 0.0635 | 0.0629 | 0.0546 | 0.0515 | 0.0591 | 0.0465 | 0.0477 |

| | A (1220-1350) | B (1340-1500) | C (1450-1600) | D (1550-1600) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) |
|----|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| CV | 5.92 | 5.60 | 7.05 | 5.00 | 6.44 | 7.62 | 8.44 | 15.57 |

| | A (1220-1350) | B (1340-1500) | C (1450-1600) | D (1550-1600) | E (1600-1700) | F (1650-1725) | G (1700-1800) | H (1800-1900) |
|----|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| CV | 5.92 | 5.60 | 7.05 | 5.00 | 6.44 | 7.62 | 8.44 | 15.57 |

Figure 1: location of sites within the medieval city of London and its local environs. The light grey hashed-line indicates the boundary used for the city. Points within the hashed-line are defined as being from the city. Points to the north represent Islington and Hackney; to the west Westminster and south of the river Thames Southwark.

Figure 2: log-scaled comparison of phase B2 (1400-1500) cattle metapodial breadth measurements from STE95 and contemporary sites.

Figure 3: comparison of log-scaled sheep post-cranial bone measurements from the Northern Suburbs in phase E (1600-1700); the difference in size is statistically significant ($U=3423$; $P=0.000$).

Figure 4: mean log-scaled cattle post-cranial bone measurements by phase. The phase B2 dump of cattle metapodials from STE95 has been excluded.

Figure 5: mean log-scaled cattle post-cranial bone measurements (lengths, breadths and depths combined) between sub-phases A1 (1220-1350) and A2 (1340-1500)

Figure 6: temporal change in cattle horncore shape based on the classification set out in Sykes and Symmons (2007)

Figure 7: mean log-scaled sheep post-cranial bone measurements by phase.

Figure 8: mean log-scaled pig post-cranial bone measurements by phase (all measurements combined).

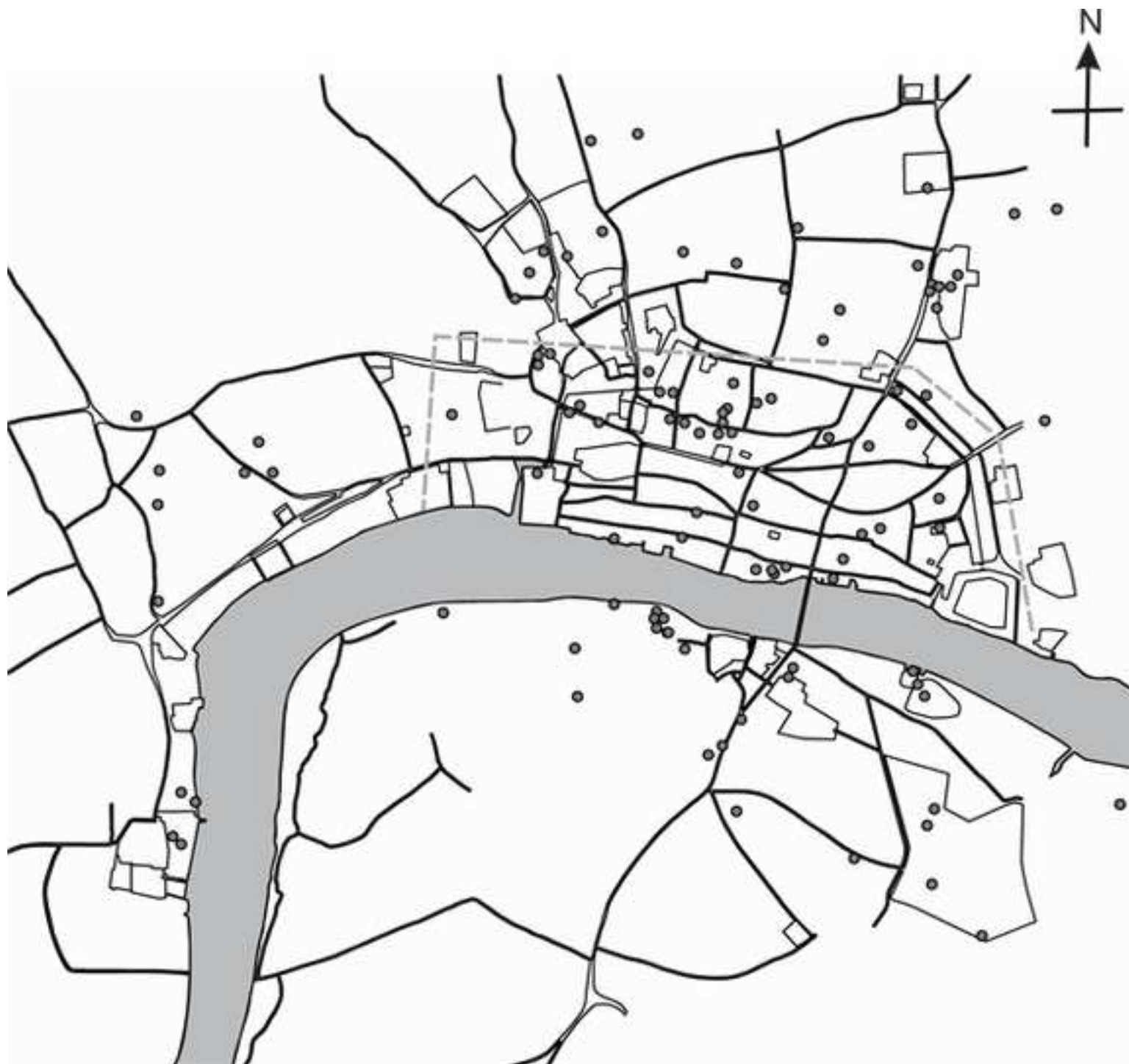
Figure 9: mean log-scaled domestic hen post-cranial bone measurements by phase.

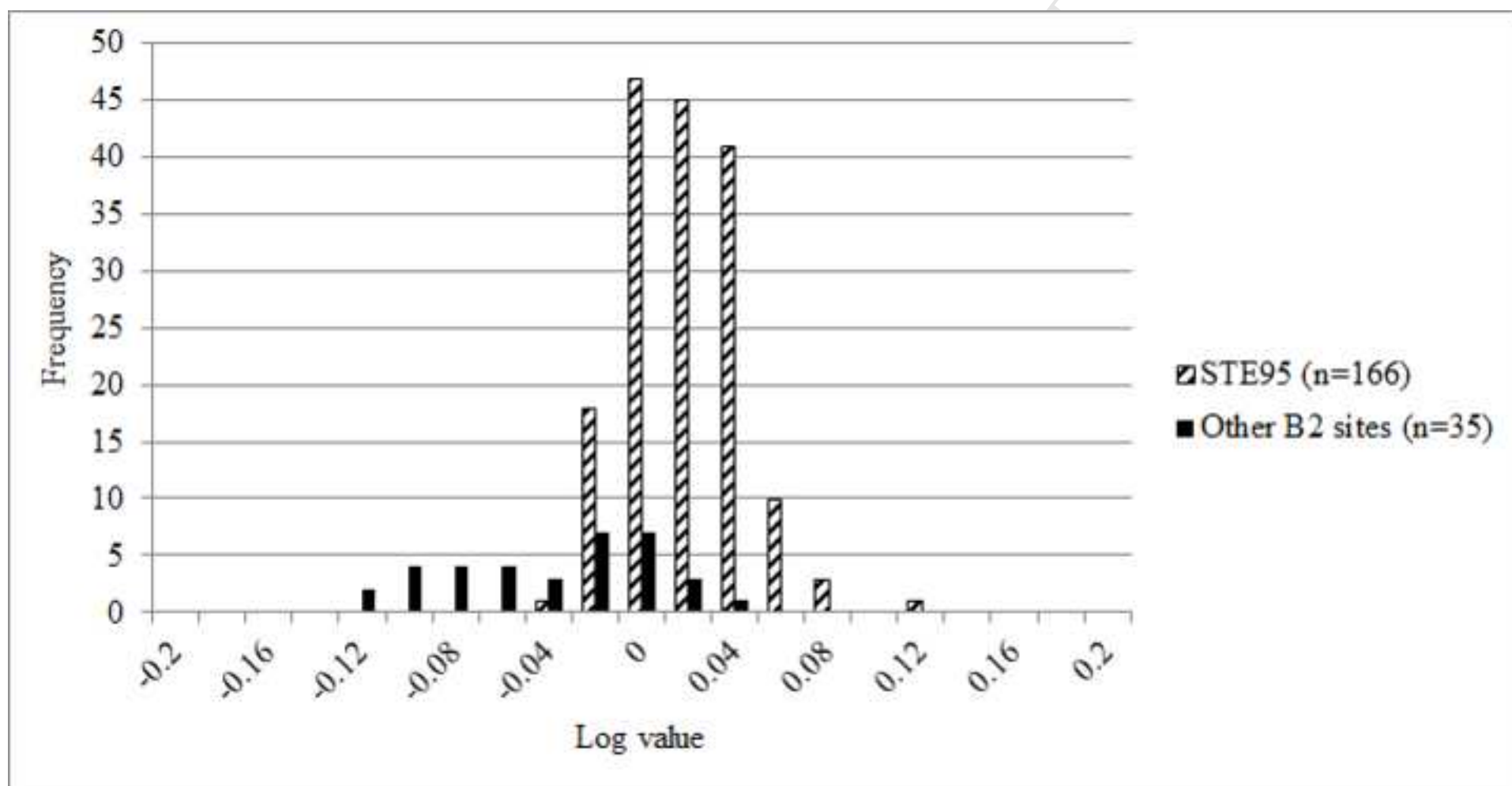
Figure 10: size-independent scatterplot of metacarpal measurements (Albarella, 1997a). Key: SD=smallest diameter of the shaft; GL=greatest length; Bd=greatest breadth of distal end.

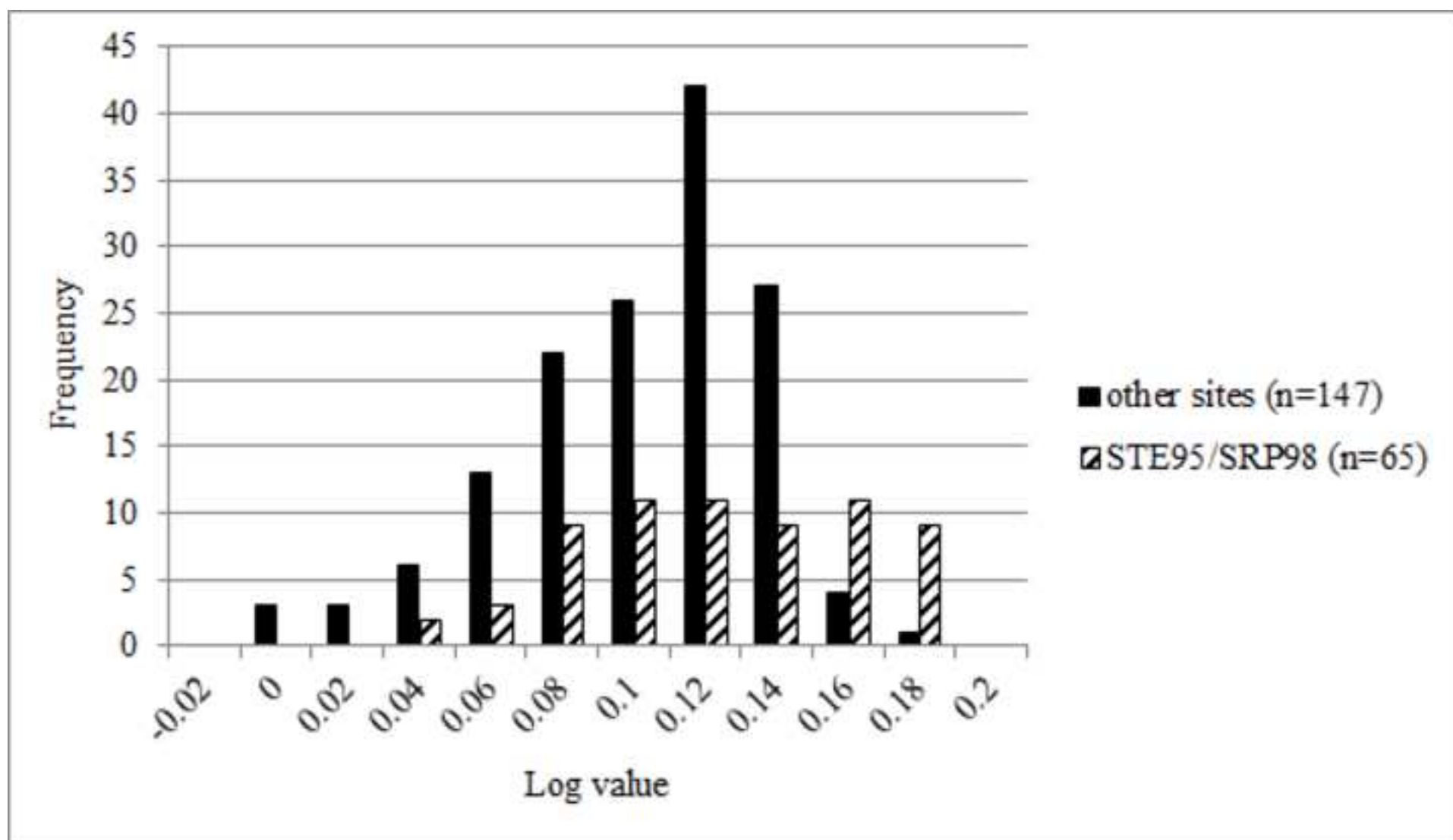
Figure 11: analysis of sex in cattle based on horncore measurements. The line follows the division of male and female cattle horncores in modern animals of known-sex (after Sykes and Symmons, 2007), and maps closely a constriction in the data, most likely the result of sexually dimorphic differences in horncore size.

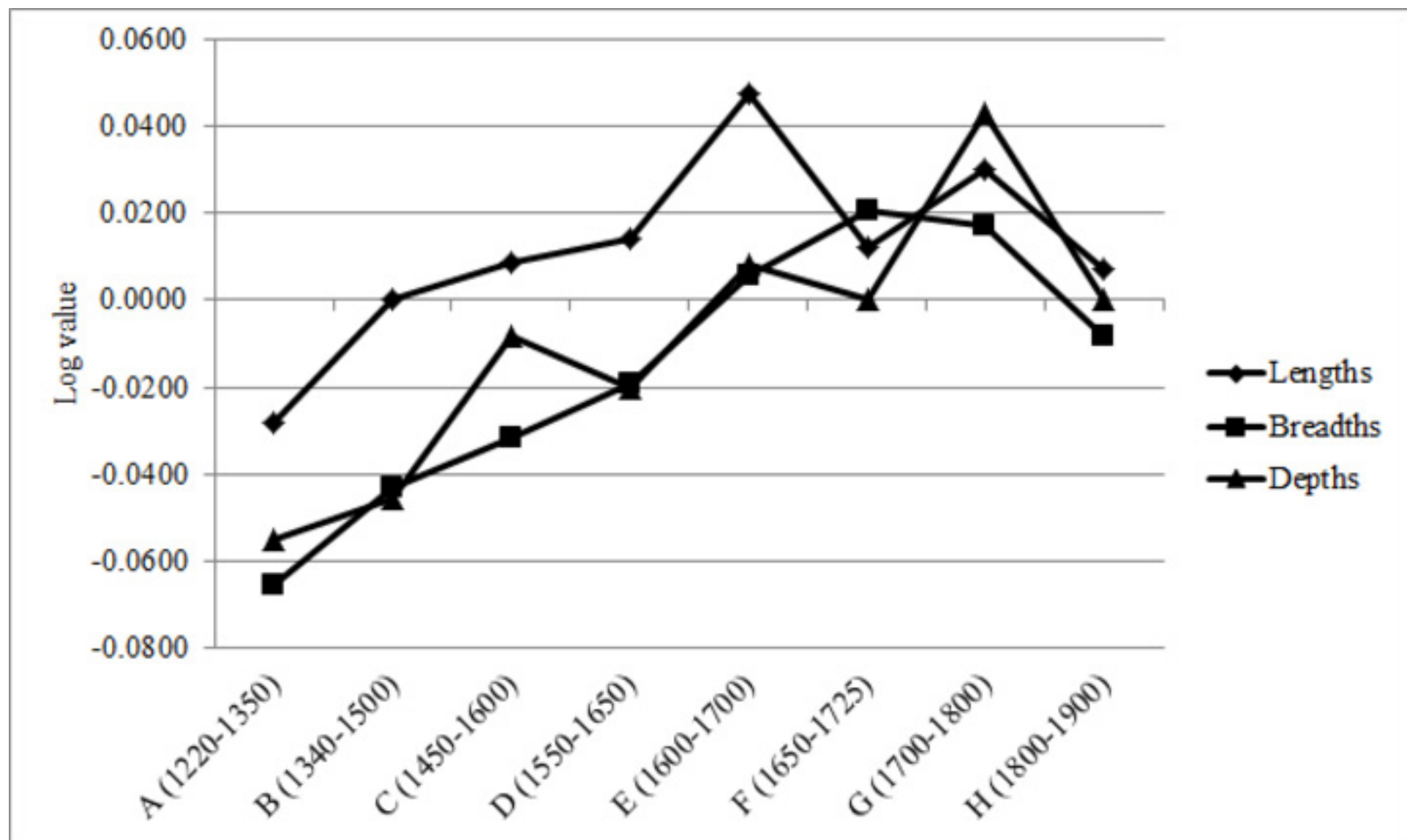
Figure 12: slenderness index of sheep metacarpal measurements. The axial divisions follow Guintard and Lallemand (2003) for females.

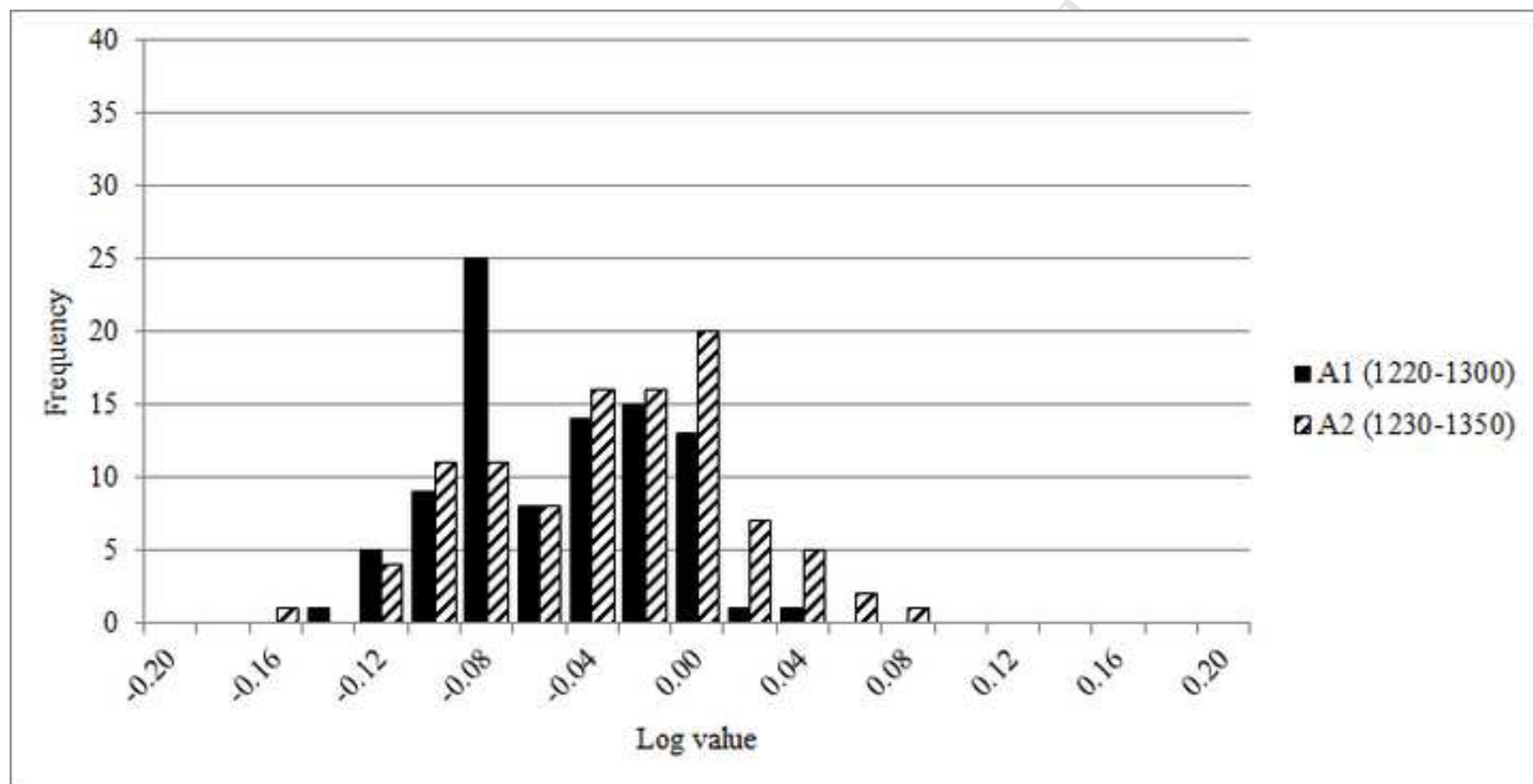
Figure 13: Analysis of sex in domestic hen by phase, based on a combination of spur formation and body tarsometatarsus size.

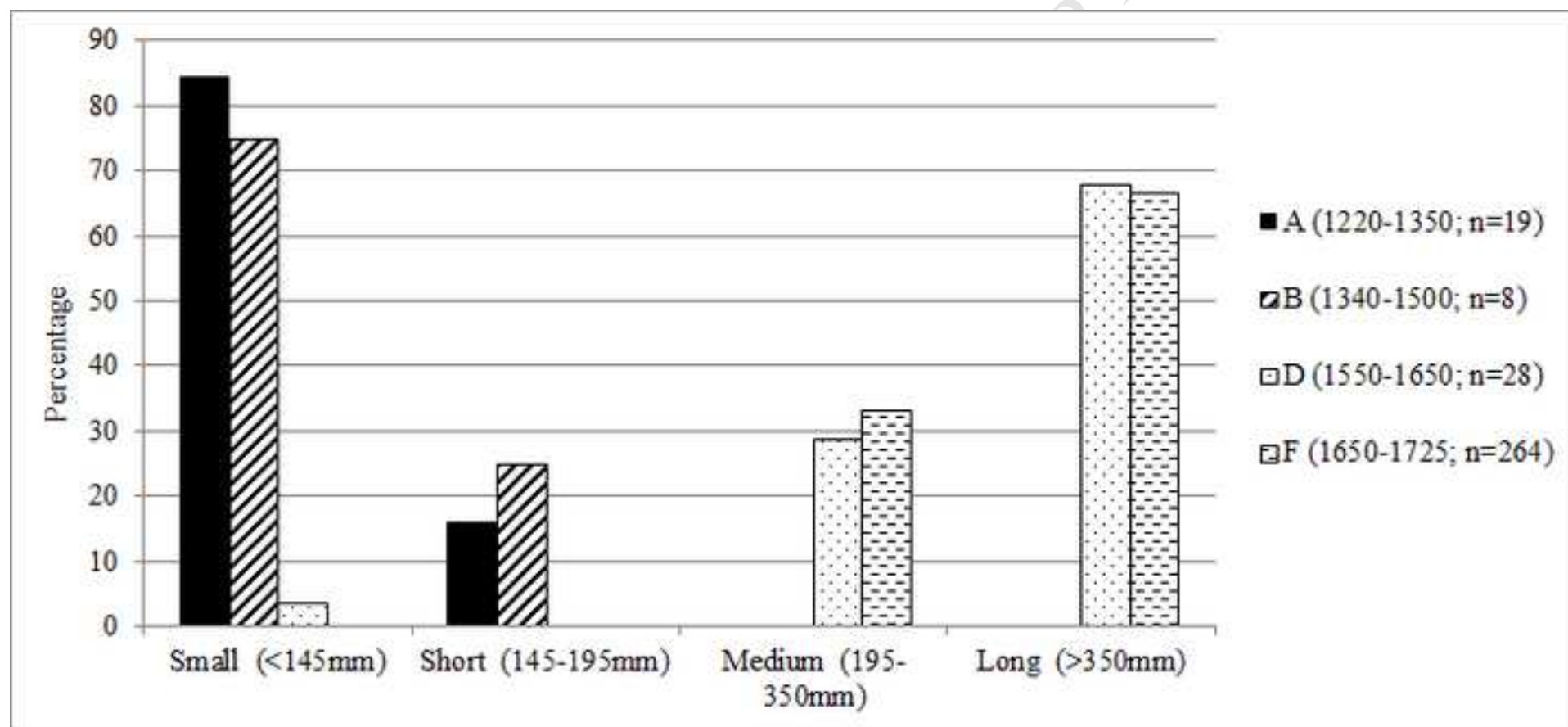


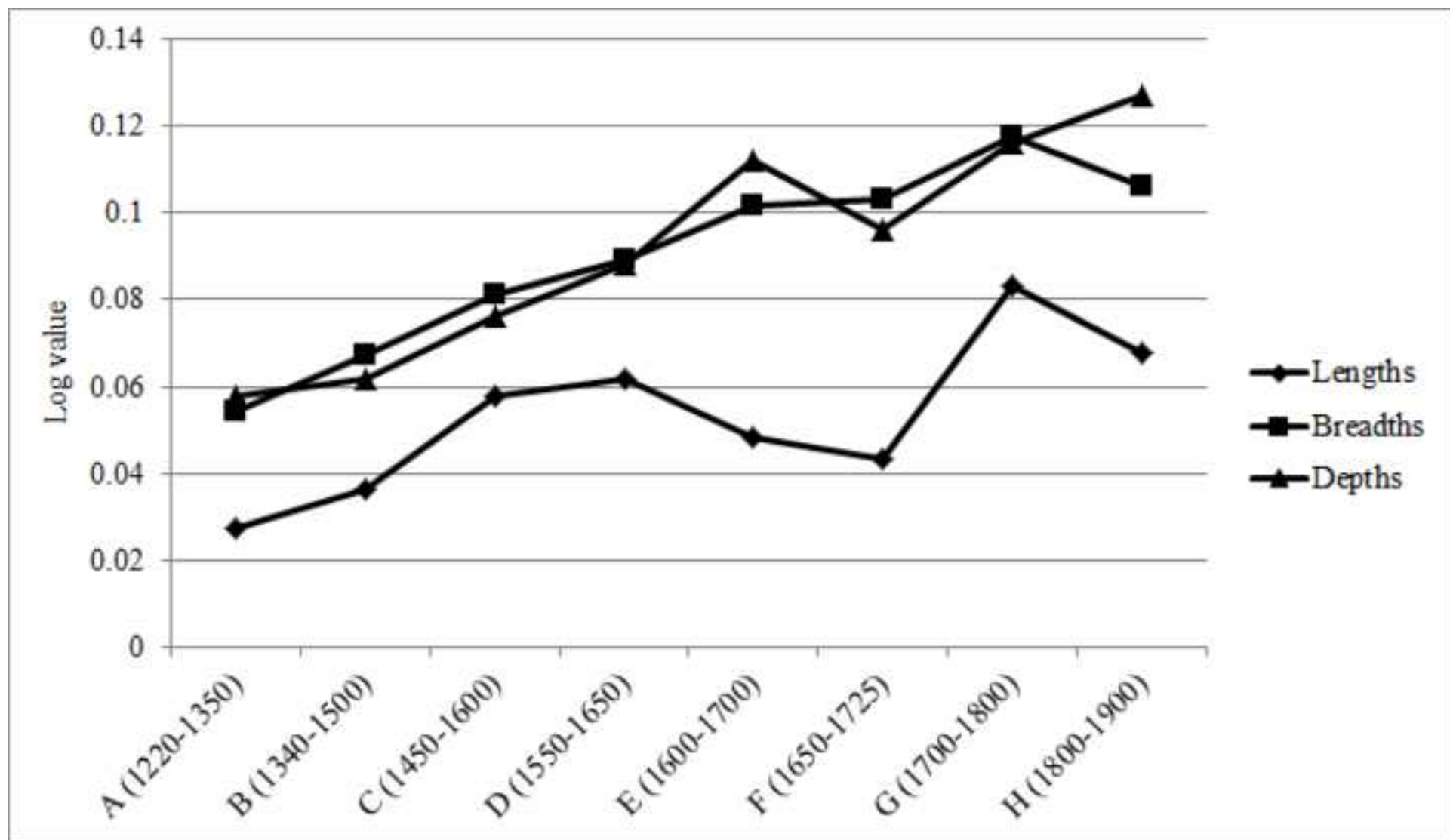
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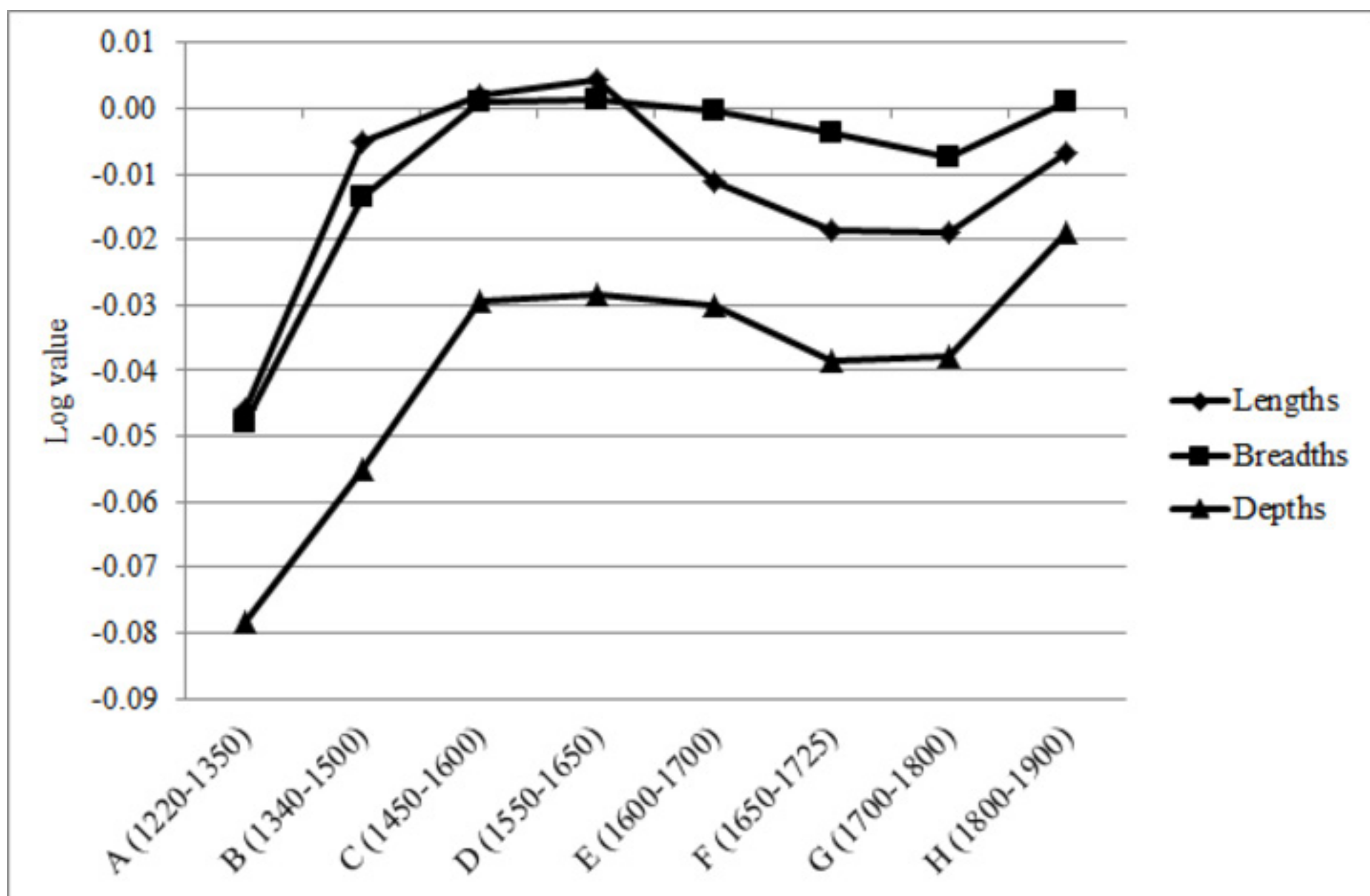


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